Protecting Feeders With Distributed Resource

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Background

- Several Hundred Mega Watts of distributed PV

- Distribution Grid is no longer radial

- Protection Considerations
Agenda

- Quick Review
- Protection considerations
- Reclosing
- Inverters vs Rotating Mass
- Challenges
- Directionality with PV
Protection Considerations

- Complete coverage
  - Relay Reach

- Minimize outages
Protective Reach

- No Dead Zones
Protective Reach

- No Dead Zones
- Verify Relay trips for Ph-Ph Fault
Protective Reach

- No Dead Zones
- Verify Relay trips for Ph-Gr Fault
Protective Reach

*Plotted in CAPE

Ph-Ph

Ph-Gr
Minimize Outages

- Selectivity
- TOC Coordination
  - Upstream
  - Downstream
Upstream TOC Coordination

- Trip feeder before transformer fuse begins to melt
Upstream TOC Coordination

- Trip feeder before transformer fuse begins to melt

- Verify Ph-Ph Fault
Upstream TOC Coordination

- Trip feeder before transformer fuse begins to melt

- Verify Ph-Gr Fault
Upstream TOC Coordination

*Plotted in CAPE

- **Ph-Ph**
  - 43 CYC
  - 28 CYC
  - 835 A
  - 3610 A

- **Ph-Gr**
  - 114 CYC
  - 22 CYC
  - 535 A
  - 4615 A
Downstream TOC Coordination

- Fuse should melt before feeder relay sends trip

- Trip Saving Scheme
Downstream TOC Coordination

- Fuse should melt before feeder relay sends trip
- Trip Saving Scheme
- Verify 3-Ph Fault
Downstream TOC Coordination

- Fuse should melt before feeder relay sends trip
- Trip Saving Scheme
- Verify Ph-Gr Fault
Downstream TOC Coordination

*Plotted in CAPE*
What happens when we add PV?

- How is relay reach affected?

- How TOC coordination affected?
Effects on Relay Reach

- Infeed
  - Accounts for a portion of the voltage drop to the fault
  - Fault current provided by Substation reduces
Effects on Relay Reach

- Infeed
  - Accounts for a portion of the voltage drop to the fault
  - Fault current provided by Substation reduces
  - Recheck Ph-Ph Fault
Effects on Relay Reach

- Infeed
  - Accounts for a portion of the voltage drop to the fault
  - Fault current provided by Substation reduces
  - Recheck Ph-Gr Fault
Effects on Relay Reach

*Plotted in CAPE

Ph-Ph

200 CYC

1220 A

Ph-Gr

565 CYC

Ground TOC Curve

I_{PH} = 895 A

Phase TOC
Effects on Relay
Reach

- The infeed desensitizes the Substation relay
- Fault clearing times could become very high
- The relay might not reach the entire zone of protection
Does it adversely affect coordination?

- Source is intermittent
- We need to protect for the worst case
- PV may only be used against you
PV may only be used against you

- Remove infeed to downstream devices when coordinating with Substation Relay
PV may only be used against you

- Remove infeed to downstream devices when coordinating with Substation Relay
PV may only be used against you

- Do not remove the PV when coordinating the feeder reclosers with downstream fuses
## Coordination and Reach Summary

<table>
<thead>
<tr>
<th>Time in Cycles</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reach Trip Time Ph-Ph</td>
<td>115</td>
<td>200</td>
</tr>
<tr>
<td>Reach Trip Time Ph-Gr</td>
<td>345</td>
<td>565</td>
</tr>
<tr>
<td>Upstream CTI</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Downstream CTI</td>
<td>17</td>
<td>17</td>
</tr>
</tbody>
</table>

*CTI: Coordination Time Interval*
Inverters vs Rotating Mass

- PV behaves like a current source
- Inverters have no inertia
- Zero-sequence and negative-sequence current suppressed
- Positive-sequence current limited
I_1,PV limited

I_2,PV suppressed

I_0,PV exists via Ground Transformer
Sequence Networks

- $I_{1,PV}$ limited
- $I_{2,PV}$ suppressed
- $I_{0,PV}$ exists via Ground Transformer

Ph-Gr Fault
Sequence Networks

I₁,ₚᵥ limited

I₂,ₚᵥ suppressed

Ph-Ph Fault
DER Employs Anti-Islanding

- IEEE 1547 states DER should shut down in less than two seconds if Utility source is lost

- UL 1741 certification
Transfer Trip

- Rotating Mass on same distribution grid

- Transfer Trip to avoid islanding
Reclosing Considerations

- Distributed resource includes Anti-Islanding Protection
- Do not reclose before the Anti-Islanding operates
- Load-to-Generation ratio – Supervision may not be necessary if the minimum load exceeds the DER by an adequate threshold
Supervision Options

- Dead Line Only
- Hot Bus – Dead Line
- Synchronous Voltage
- Potential Required
- Be mindful of upstream reclosing
Substation Considerations

- Use caution with ATO Schemes
  - Allow Anti-Islanding Protection to operate before throwing over to Back-up Transformers
  - Add supervision or a time delay to operation

- Ensure voltage regulators support bi-directional flow and set them accordingly
Challenges Encountered

- Modelling the PV DER
  - Gathering necessary information in allotted time
  - Nonconventional system parameters

- Quantity of installations over limited time period
  - Hundreds of MW installed in a 2 year span
Challenges Encountered

- Smaller fused distribution transformers leave very little or no budget to squeeze consecutive protective zones
  - Transformer fuse to Feeder relay to downstream recloser to solar garden fuse

- Some reclosers fit the desired standard installation better than others

- Sorting out whether issues were existing or caused by the PV insertion
Should directionality be utilized?

- Reverse looking directional element set more sensitive than non-directional element
  - PV will not provide negative sequence current

- Reverse looking directional element to supervise reclosers
  - Directionality is inherent simply based on magnitude
  - PV supplies 1.1 – 1.3 p.u. current under fault condition
Questions?
System Parameters
## System Parameters

### A - Source
- **Voltage**: 69 kV
- **MVA**: 100
- **$R_1$**: 0.04201 pu
- **$X_1$**: 0.16803 pu (Subtransient)
- **$R_0$**: 0.03151 pu (Subtransient)
- **$X_0$**: 0.1890 pu

### B - High Side Fuse
- **Speed Class**: Slow
- **Designation**: 100E

### C - Distribution Transformer
- **69 kV – 13.8 kV**
- **Dyg1**
- **MVA**: 8.4/10.5
- **$Z_1$**: 7%
- **$Z_0$**: 6%

### D - Feeder Relay TOC Curves
- **Phase Pick-up**: 672 A
- **Phase Time Dial**: 1.2
- **Phase Curve**: U.S. Inverse
- **Ground Pick-up**: 480 A
- **Ground Time Dial**: 7
- **Ground Curve**: U.S. Very Inverse
# System Parameters

## E - Line Segment
- $R_1$: 0.07194 pu
- $X_1$: 0.17223 pu
- $R_0$: 0.24890 pu
- $X_0$: 0.60360 pu

## F - Branch Fuse
- Speed Class: T
- Designation: 140T

## G - Line Segment
- $R_1$: 0.57551 pu
- $X_1$: 1.37786 pu
- $R_0$: 1.99118 pu
- $X_0$: 4.82882 pu

## H - Line Segment
- $R_1$: 0.03597 pu
- $X_1$: 0.08612 pu
- $R_0$: 0.12445 pu
- $X_0$: 0.30180 pu

## I - Recloser TOC Curves
- Phase Pick-up: 300 A
- Phase Time Dial: 2
- Phase Curve: U.S. Very Inverse
- Ground Pick-up: 150 A
- Ground Time Dial: 7
- Ground Curve: U.S. Very Inverse
System Parameters

J - Inverter Step-up Fuse
Speed Class T
Designation 40T

K - Ground Transformer
* 5 parallel transformers
Zig-Zag
MVA 1
Base kV 13.8
R0 0.03 pu
X0 0.6 pu

L - Inverter Step-up (ISU) Transformer
* 5 parallel transformers
13.8 kV – 480 V
Yd1
MVA 1
Z1 6%
Z0 6%

M - Lump PV Source and Inverter
* 5 parallel sources
Voltage 480 V
MVA 1
R1 0.0 pu
X1 0.217 pu (Subtransient)
R2 Infinite
X2 Infinite
R0 Infinite
X0 Infinite
Current Limit 1.2 pu
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